SNOOPY: Student Nanoexperiments for Outreach and Observational Planetary InquirY[1,2]

Kimberly R. Kuhlman, Michael H. Hecht,
David E. Brinza, Jason E. Feldman, Stephen D. Fuerstenau
California Institute of Technology,
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109
818-354-2902
kkuhlman@jpl.nasa.gov

Louis Friedman, Linda Kelly, Jeffery Oslick,
Kevin Polk, Lucas E. Möller, Kelly Trowbridge,
Jessica Sherman, Adam Marshall, Andre Luis Diaz
The Planetary Society
Pasadena, CA 91106-2301

Anna Waldron
Cornell University
Ithaca, NY 14853

Collin Lewis, Csaba Gyulai, George Powell
Visionary Products, Inc.
11814 South Election Drive, Suite 200
Draper, UT 84020

T. Meloy
West Virginia University
Morgantown, WV 26506

P. Smith
The University of Arizona
Tucson, AZ 85721

Abstract—Student Nanoexperiments for Outreach and Observational Planetary Inquiry (SNOOPY) is an example of directly involving students and teachers in planetary science missions. The SNOOPY Project evolved from the Mars Environmental Compatibility Assessment (MECA) Student Nanoexperiment Project, a partnership between MECA, The Planetary Society and Visionary Products, Inc. The MECA instrument suite, developed at the Jet Propulsion Laboratory, was scheduled for launch aboard the canceled Mars Surveyor Lander 2001. Students 18 years of age and younger were invited to propose experiments that were consistent with MECA's Mission: *to help us better understand how humans will be able to live on Mars.* Two nanoexperiments were chosen for flight, the Angle of Repose of Martian Dust and Contradistinctive Copper. These experiments addressed the behavior of windblown Martian dust on surfaces and the oxidation of copper. The SNOOPY paradigm for planetary science experiments could be used on a variety of future space exploration missions.

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1. INTRODUCTION

As scientists and engineers, we are generally too busy trying to scrounge an existence out of ever shrinking budgets to think about, much less contribute to, communicating with the general public. As scientists and engineers primarily employed by the public, however, we have a responsibility to "communicate the results of our research so that the average American could understand that NASA is an

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investment in our future..." [1]. Not only is the public our employer, it is also the source of future generations of scientists and engineers.

Many of us owe our career choices to those special scientists and engineers who took it upon themselves to reach out to tell the story of our solar system and our universe in a way that we could understand. We can honor our commitment to communicate with the public, whether through agency-sponsored education and public outreach (E/PO) projects, or through creative new initiatives that involve educators and students in our research and exploration. Substantial funding is allocated to E/PO associated with many high-profile missions and programs, but these resources often are not available to individual scientists and engineers in their everyday work. Education and public outreach would benefit from funding and incentives for scientists and engineers who want to get involved, but lack the resources.

The NASA Implementation Plan for Education 1999-2003 (1998) describes several ways in which NASA content may be delivered to the formal and informal education communities. Two of the goals are:

> "To use the NASA mission, facilities, human resources, and programs to provide exposure to teachers and faculty to support the enhancement of knowledge and skills, and to provide access to NASA information in science, mathematics, technology engineering, and geography," and

> "To develop, utilize, and disseminate science, mathematics, technology, and geography instructional materials based on NASA's unique mission and results, and to support the development of higher education curricula."

Teachers typically don't have the time or expertise to research recent advances in space science and reduce them to a form that students can absorb. Teachers are also often intimidated by both the subject and the researchers themselves. Therefore, the burden falls on us -- the space scientists and engineers of the world -- to communicate our findings in ways both teachers and students can understand. Student Nanoexperiments for Outreach and Observational Planetary Inquiry (SNOOPY) provides just such an opportunity to directly involve our customers in planetary science missions.

2. History

A prototype for payload integrated education and public outreach projects on planetary science missions, SNOOPY follows a long history of NASA educational programs that allow students to fly experiments in space. The NASA Getaway Special (GAS) program has been deploying student experiments for almost 30 years. The NASA Student Involvement Program (NISP) is an annual competition in which students in grades 9-12 can propose experiments to fly on either the Space Shuttle or a sounding rocket. New programs will help students fly their experiments aboard the International Space Station (ISS). However, these programs only provide access to low Earth orbit (LEO). The SNOOPY project extends this modular concept to planetary missions.

The SNOOPY project is the current incarnation of an outreach project of the Mars Environmental Compatibility Assessment (MECA) project. The MECA instrument suite, developed at the Jet Propulsion Laboratory (JPL), was scheduled for launch aboard the canceled Mars Surveyor Lander 2001 (Figure 1). The MECA payload was sponsored by NASA's Human Exploration and Development of Space (HEDS) Enterprise. The original MECA Student Nanoexperiments were to be tiny, autonomous experiments proposed and developed by students and incorporated into the MECA Patch Plate (Figure 2).

The MECA Patch Plate was designed to study the interaction of materials and structures to the Martian environment, with emphasis on dust adhesion. The Patch Plate, which sits on top of the MECA instrument box, holds 72 individual tokens or patches, each 1 cm in diameter and up to 1 cm deep. Lacking any electronic interface, the Patch Plate was to be deployed by the Lander's Robotic Arm, which could also be used to shake loose excess soil. Changes in the patch surfaces were to be observed with the Robotic Arm Camera (RAC). The patches include calibration targets for the RAC and various spacesuit and construction materials.

The MECA Student Nanoexperiment Project was a partnership between MECA, The Planetary Society (TPS) and Visionary Products, Inc. (VPI). The time available for the competition, construction of winning designs and integration into the MECA payload was very short, about 12 months. The Planetary Society released an Announcement of Opportunity on the World Wide Web, inviting students 18 years of age and younger to propose experiments that were consistent with MECA's Mission: "to help us better understand how humans will be able to live on Mars." The competition was also announced through press releases and organizations of science and mathematics teachers. Each nanoexperiment was constrained to fit into a single hole in the Patch Plate, have a mass of 3 g or less, require no power, and require only a single image by the Mars Surveyor 2001 RAC. The students, as individuals or teams of up to three, were asked to submit both a short proposal and a prototype of their experiment.

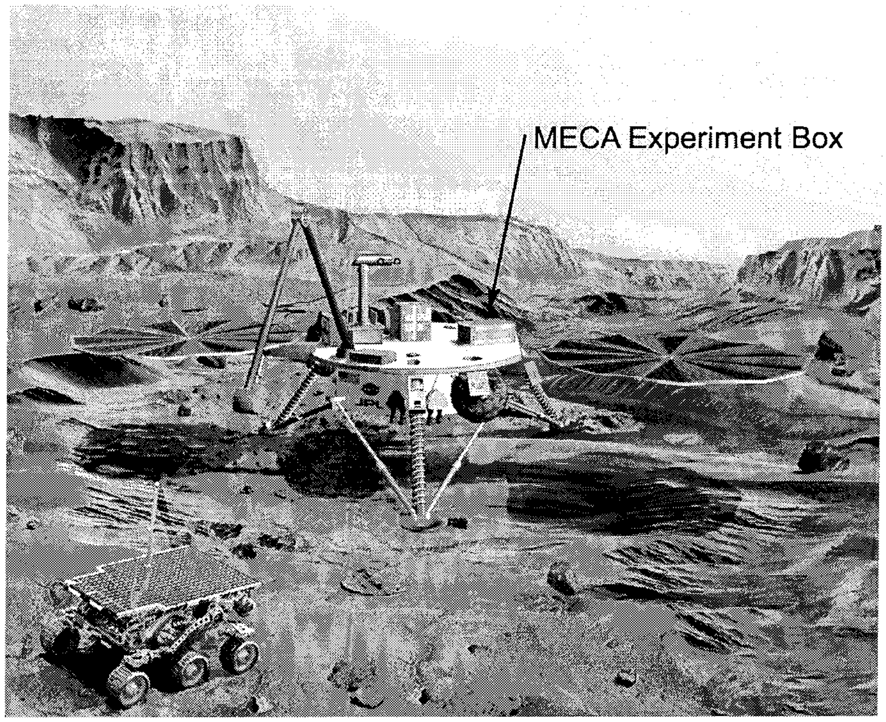

Figure 1. Artist's rendering of the Mars Surveyor 2001 Lander (Adapted from artwork by Corby Waste, JPL).

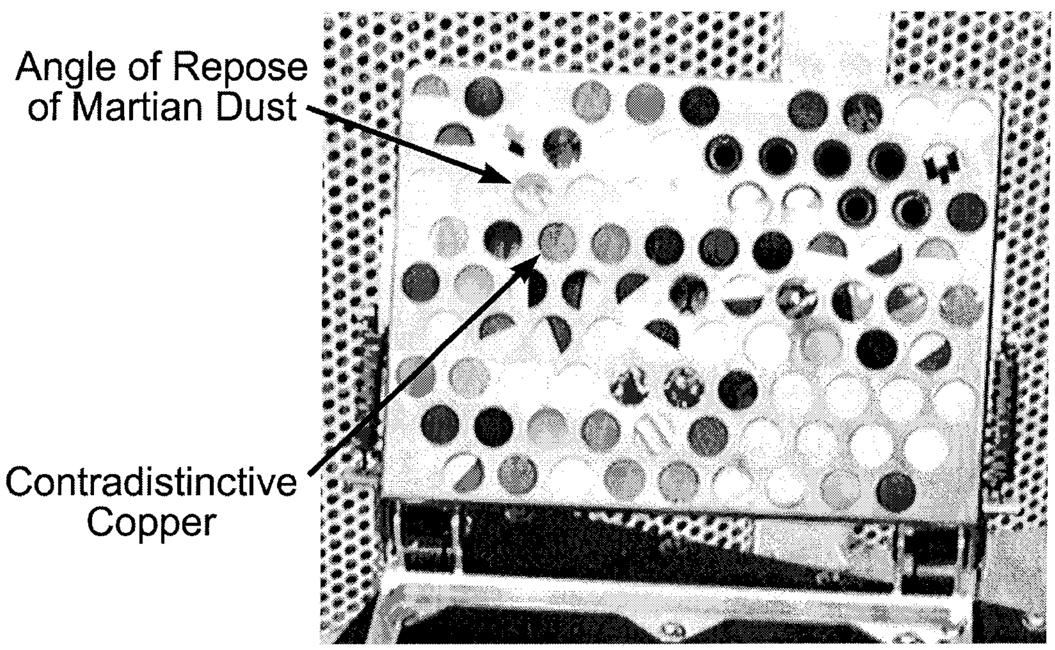

Figure 2 - The completed MECA Patch Plate with the Student Nanoexperiments indicated.

While most entries came from the United States, several were received from Canada, Australia, Brazil, Israel, Japan and the United Kingdom. Two finalists and an alternate were selected based on scientific merit, feasibility and relevance to MECA's mission. Chosen for flight were the "Angle of Repose of Martian Dust," proposed by Lucas Möller of Moscow, Idaho (Figure 3a) and "Contradistinctive Copper," proposed by Jessica Sherman and Kelly Trowbridge of Lansing, New York (Figure 3b). These experiments addressed the behavior of windblown Martian dust on surfaces and the oxidation of different textures of a possible building material, respectively. An alternate nanoexperiment was derived from similar proposals submitted by Adam Marshall of Chapel Hill, North Carolina and Andre Luis Diaz of São Paulo, Brazil, who each proposed to observe the behavior of spacesuit materials in the Martian environment.

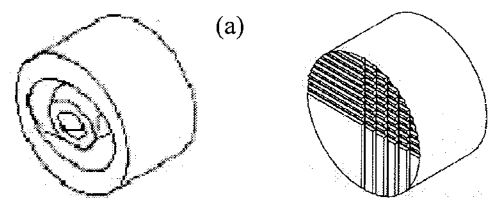

Figure 3. (a) Schematic diagram of the Angle of Repose nanoexperiment. (b) Schematic of the Contradistinctive Copper nanoexperiment. Courtesy of VPI.

An important goal of the MECA Student Nanoexperiments Project was publication of the results of the students' work in the scientific literature. Despite the cancellation of Mars Surveyor 2001, Lucas Möller presented the results of his initial calibration experiments using JSC-1 lunar simulant [2] and JSC Mars-1 simulant [3] at the 32nd Lunar and Planetary Science Conference in Houston, March 2001 () [4].

Figure 4. Lucas Möller (center) presenting the results of the Angle of Repose nanoexperiment at the 32nd Lunar and Planetary Science Conference, Houston, Texas, 2001.

3. Angle of Repose Nanoexperiment

Wind-blown dust will be a considerable challenge in the exploration of Mars. The lifetime and power output of solar cells and the durability of instruments and materials require an understanding the angle of repose of Martian dust. For example, the Materials Adherence Experiment (MAE) measurements on Pathfinder indicated steady dust accumulation at a rate of about 0.28% per day [5]. This observation is consistent with the decrease in power derived from the solar panels, estimated at 0.29% per day [5]. The angle of repose nanoexperiment was designed to provide information about the ideal angle at which solar panels can be positioned to minimize dust deposition and thus, maximize the power output and lifetime of the solar cells.

Airborne particles deposited on surfaces interact with the surface and with other particles. The angle of repose is defined as the "steepest angle of a surface at which a mass of loose or fragmented material will remain standing in a pile on a surface, rather than sliding or crumbling [6]." A sandpile with slope equal to the angle of repose is in a metastable configuration which become unstable if perturbed [7]. A large literature exists concerning the experimental and numerical study of the behavior of granular solids. The angle of repose has been demonstrated to be dependent on the many variables [8,9] including the density of the material [10], humidity [11], packing history [12], boundary conditions [8,12], coefficient of sliding friction [13,14], coefficient of rolling friction [15], density of particles [16], and particle characteristics such as size [17,18] and shape [16,19]. The method by which the "sandpile" is formed also influences the angle of repose [20]. Deconvolving these variables to determine their roles in a particular measurement is difficult at best, and empirical equations are needed to relate the angle of repose to the variables for engineering applications. Empirical equations have recently been formulated and validated through numerical and physical simulations [21]. However, these equations have yet to be published.

Experimental Approach

Circular surfaces, such as cylinders and spheres, provide a full range of tangent angles for a simple measurement of the angle at which deposited dust will no longer adhere. A solid 1 cm x 1 cm aluminum cylinder was machined to present concentric cylindrical surfaces at the 52° open angle of the MECA experiment bay (Figure 3a). The design allows for six points of dust angle measurements on the inner and outer cylindrical surfaces. Dust collection over the mission term is expected to be a function of the angle of repose. The lander robotic arm camera would take high-resolution images for graphical analysis. The angle of repose instrument was successfully flight tested and incorporated into the MECA Patch Plate.

Laboratory experiments

The critical angle measurement instrument was tested with Martian Regolith Simulant JSC Mars-1 and Lunar Regolith Simulant JSC-1 [4, 5]. Although windblown Martian dust is estimated to have a radius of < 2 μm, the simulants used in all tests were consisted of the < 75 μm size fraction [6]. The simulants were placed in stacked 150 μm and 75 μm sieves and agitated 0.5 m above and 0.5 m to the side of the critical angle instrument. A small laboratory air draft carried the airborne dust fraction to the instrument below. Images of the instrument after dust collection were obtained using a 2.1 megapixel digital camera and analyzed graphically. Critical angles were measured for the left (L) and right (R) sides of the convex, upper (U) concave and lower (L) concave zones of the instrument.

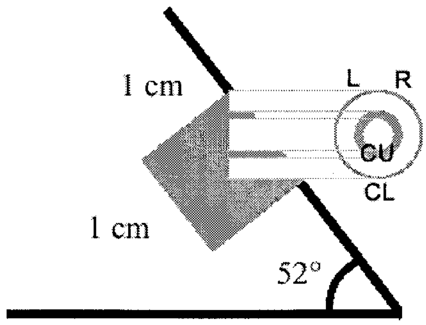

Figure 5 - Schematic diagram of the cross-section of the angle of repose nanoexperiment [Adapted from 4]. L and R denote the left and right convex surfaces while CU and CL denote the concave upper and lower surfaces respectively.

Results

The results for three tests with each of the simulants are shown in Table 1 and Table 2. The average measurement for both concave surfaces are within the standard deviations measured for both simulants. Distinctly different values were measured for the convex surfaces and the concave surfaces. The standard deviations are relatively large indicating that a greater number of measurements are needed.

Table 1 - Angles of repose measured for martian regolith simulant JSC Mars-1.

	L1	R1	L2	R2	L3	R3	AVG	SD
Convex	28.5	33.5	35.0	43.5	29.0	34.5	34.0°	5.4°
Concave U	63.0	64.5	54.0	44.0	41.5	57.0	54.0°	9.6°
Concave L	57.0	54.5	50.5	48.5	54.5	54.5	53.3°	9.6°

Table 2 - Angles of repose measured for lunar regolith simulant JSC-1.

	L1	R1	L2	R2	L3	R3	AVG	SD
Convex	18.5	34.5	32.5	34.0	33.0	45.0	32.9°	8.5°
Concave U	58.5	44.0	41.0	43.0	54.5	54.5	49.3°	7.4°
Concave L	49.0	72.0	52.0	52.5	54.0	44.5	54.0°	9.4°

Conclusions

The average measurements of the angle of repose for JSC Mars-1 and JSC-1 using the angle of repose nanoexperiment appear to be independent of the simulant used. This observation is likely due to the method of drifting the < 75 μm size fraction to the instrument. Smaller particles travel further in the air stream while larger particles may not have reached the instrument. If we assume that the humidity, particle size and boundary conditions are the same throughout the experiments, the measured angle of repose is a function of particle shape, coefficients of sliding and rolling friction and the cohesive forces between the particles (e.g. electrostatic forces). The particle shape and texture of the particle surfaces is as yet unknown, but will be characterized using scanning electron microscopy (SEM) in future work. To determine the effect of electrostatic forces on the angle of repose, future experiments will be performed using a ceramic instrument.

Decreasing the width of a container holding a sandpile results in forces between the particles and the walls which in turn increase the angle of repose [8]. This effect is clearly observed in the measurements shown in Table 1 and Table 2. The angles of repose measured on the concave surfaces are about 20 degrees greater than those measured on the convex surfaces. The convex surface provides an essentially containerless environment in which the sandpile can form. The effect this surface has on the angle of repose versus a flat-bottomed container has yet to be determined, and will be addressed in future work.

As a final point, the gravity of Mars is 37.7% of Earth's and thus may affect the angle of repose. However, the physical properties and cohesive forces of Martian dust are expected to dominate the angle of repose.

4. CONTRADISTINCTIVE COPPER

Oxidation of materials is of major concern for the future exploration of Mars and for the search for past or present life on Mars. The presence of a "superoxidant" has been hypothesized from Mars Pathfinder and Viking data, but the nature of the oxidant is unknown. Reactivity of engineering materials such as copper in the martian environment must be considered in the design of spacecraft and equipment for the future exploration of Mars, particularly where humans are involved.

The Contradistinctive Copper nanoexperiment was proposed by Kelly Trowbridge and Jessica Sherman (Figure 6) as a simple way to characterize the extent of the oxidizing environment on the surface of Mars (Figure 3b and Figure 7). Each quadrant of the experiment is fabricated with a different texture to provide variable surface area for corrosion and to interact with wind-blown particles.

Experimental Approach

Initial calibration experiments are just getting started for the Contradistinctive Copper nanoexperiment and consist of a series of experiments with freshly cleaned copper exposed to environments independently simulating each of the variables expected in the Martian environment. These variables include temperature, atmospheric composition, incident ultraviolet (UV) radiation and oxidizing species. The first experiment involved two identical pieces of copper cleaned with standard tarnish remover and dry ice. One piece of copper was placed directly on the dry ice and the other was placed on a screen 10 cm above the dry ice (Figure 8). The system was enclosed in a styrofoam container and observed daily for two weeks. The atmosphere around the samples can be assumed to be pure carbon dioxide sublimated from the dry ice. The temperature of the sample on the screen can be assumed to be higher than that of the sample in direct contact with the dry ice.

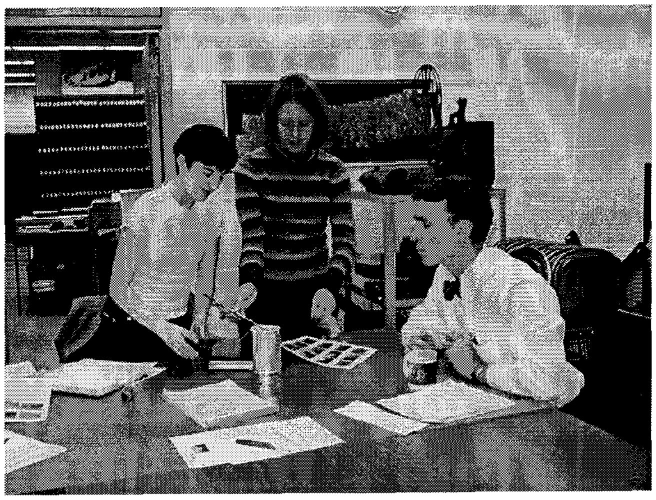

Figure 6. Kelly Trowbridge and Jessica Sherman working on their Contradistinctive Copper nanoexperiment with Bill Nye.

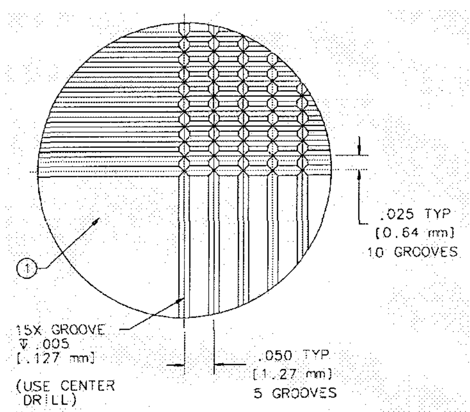

Figure 7 - Schematic diagram of the face of the Contradistinctive Copper nanoexperiment showing four different textures in each of the quadrants.

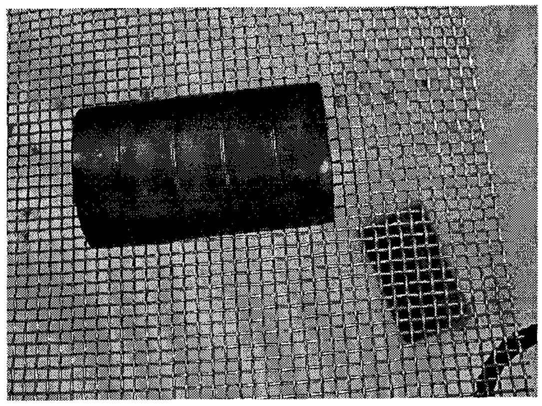

Figure 8 – Experimental configuration for initial testing of Contradistinctive Copper nanoexperiment.

Results

After six days of resting directly on dry ice, the copper began to show signs of corrosion. White spots appeared on the surface. The copper sample placed on a screen 10 cm above the dry ice did not show as many signs of corrosion. The white spots were again visible, but were lighter in appearance and less abundant. The type of corrosion responsible for these spots is unknown at present. It was also observed that the copper resting 10 cm above the dry ice was darker in overall color (Figure 9) than the sample resting directly on the dry ice (Figure 10).

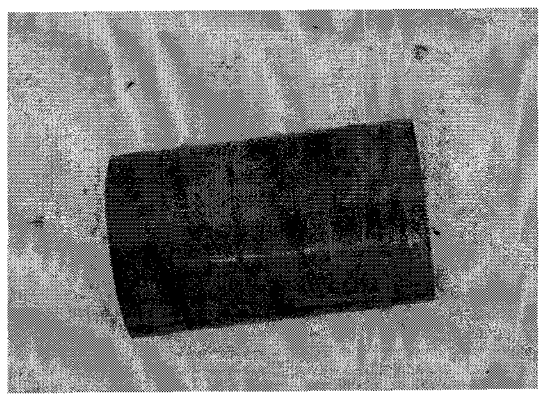

Figure 9 – Copper sample after six days resting directly on dry ice. The background is part of the styrofoam container.

The results of the initial experiment demonstrate that the copper will show visible changes within the first few days in a cold environment without a strong oxidant. The source of the corrosion observed has yet to be determined. Two types of changes were observed. First, white spots formed on both samples and were more widespread on the copper in contact with the dry ice. These features cannot be explained without microscopic examination. Second, an overall darkening of the sample held 10 cm above the dry ice occurred. This darkening may be the result of an overall oxidation of the surface. One would expect the sample at a higher temperature to oxidize more quickly.

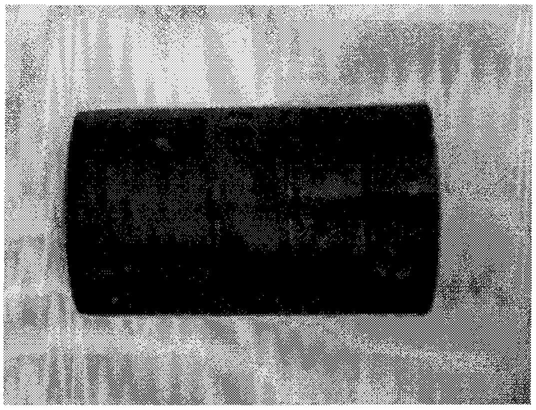

Figure 10 – Copper sample after six days on a screen 10 cm above dry ice. Note the darker overall color than the sample in Figure 9.

Future experiments

Further experiments will be conducted as part of the calibration testing for the Contradistinctive Copper experiment. These experiments will involve observing the copper samples in environments where only one of the above variables is changed. The first experiment involved only copper and gaseous and frozen carbon dioxide. The following experiments will involve only copper and UV radiation and copper and the oxidant hydrogen peroxide. Once the separate effects of each of the variables on the copper is determined, the variables will be combined to determine their collective effects. A total of six experiments will be performed culminating in the combination of all three variables. Finally, the Martian simulant, Johnson Space Center (JSC) Mars-1 [3] will be added to determine the effects of the regolith components on the copper in the presence of UV light, carbon dioxide and hydrogen peroxide. Based on the results of the above experiments, additional research may be performed in a specialized chamber at JPL in which the Martian conditions can be well controlled.

5. SNOOPY

After the loss of the Mars Surveyor 2001 Lander opportunity, the MECA team decided to redesign the nanoexperiments to interface with a generic lander (Figure 2). The new design allows for uncertainty in the final resting angle of the lander and alleviates imaging problems due to uncertain lighting conditions. We took this opportunity to add the third nanoexperiment, which has been simplified to a single fiber of Kevlar® under tension. The creep of the fiber is measured as a function of time and environmental conditions.

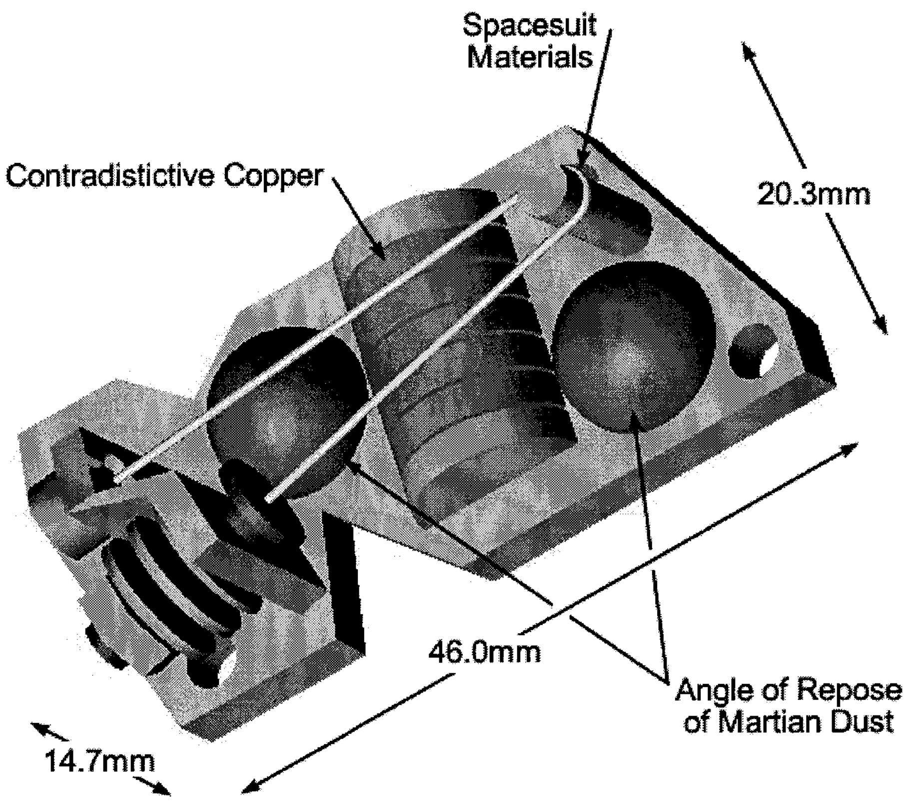

Figure 11 - Three-dimensional schematic of the redesigned SNOOPY payload (Rendering courtesy of The Planetary Society and Visionary Products, Inc.).

6. THE FUTURE

The education and public outreach goals of SNOOPY are twofold: 1) to provide opportunities for students to participate in planetary science missions and 2) to involve students worldwide in the science return and interpretation on a real-time basis. The first of these goals has been realized even though the original mission has been canceled. The second goal can be partially realized even if SNOOPY does not complete its mission. The Planetary Society and JPL plan to develop curriculum units that allow teachers and students to replicate the calibration experiments of the "student principal investigators" and to compare their results with the official calibrations. Should SNOOPY eventually fly, the images returned will be released on the World Wide Web as soon as they are made available to the investigators. Students around the world will be able to see and interpret the results and compare them to their own calibrations and to the behavior of their local materials. An online forum will allow the discussion of results.

The SNOOPY story does not have to end here. We invite future missions to Mars and other bodies in the Solar System to consider adding the SNOOPY concept to their payload. We also hope to propose a new SNOOPY competition and payload for the "Smart Lander" currently planned by NASA for launch to Mars in 2007. This version of SNOOPY will provide power and input/output capability much like the GAS modules and Space Experiment Modules (SEM). Future SNOOPY payloads may contain tiny experiments from undergraduate and graduate students as well as researchers at large, just as the GAS modules do. This next generation of nanoexperiments can benefit from advances in microelectronics and microelectromechanical systems (MEMS). Simple or complex, they will allow more people to be directly involved in planetary science missions than ever before.

7. LESSONS LEARNED

The SNOOPY project demonstrates the value a non-profit organization like The Planetary Society can add to planetary missions. In pursuit of their goal to disseminate knowledge about space exploration, TPS is able to cooperate with the space agencies of the world, translate scientific information into everyday language and reach into classrooms worldwide. By working with small engineering firms like VPI, hardware could be developed quickly and cheaply, without many of the constraints found in government programs.

By forming a partnership between small organizations, the SNOOPY team became directly involved in education and public outreach. We had the opportunity to mentor, and hopefully inspire, the future members of our community. We recommend this approach to other projects. Create small curriculum units that time-pressed teachers can easily understand and incorporate into their lesson plans. Take the time to teach the teachers about your projects. Mentor an individual or a team of students in the NASA Student Involvement Program (more information is available at http://www.nisp.net/). Make yourself available to mentor a student who is just trying to figure out what kind of a career they want to pursue.

We have a responsibility not only to explore space, but to teach the world what we do and how we do it, to share with them what we find, and to give people worldwide a sense of ownership in our accomplishments.

8. ACKNOWLEDGMENTS

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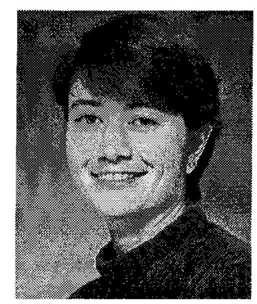
9. BIOGRAPHIES



Kimberly Kuhlman is a member of the technical staff at the Jet Propulsion Laboratory in Pasadena, California where she is the Principal Investigator for the Miniature Local Electrode Atom Probe (Mini-LEAP) project. She is also the Technical Lead for SNOOPY. Kim has a BS in Astrophysics and a BS in Physics from the University of Minnesota, a Master's degree and a Ph.D. in Engineering Physics from the University of Wisconsin. She is also an alumnus of the International Space University.

Michael Hecht is a member of the technical staff at the Jet Propulsion Laboratory in Pasadena, California and was the Project Manager for MECA.

David Brinza is a member of the technical staff at the Jet Propulsion Laboratory in Pasadena, California and has participated in the engineering of many of JPL's spacecraft.

Jason Feldman is a member of the technical staff at the Jet Propulsion Laboratory in Pasadena, California and was the principal designer of the MECA Patch Plate.

Stephen Fuerstenau is a member of the technical staff at the Jet Propulsion Laboratory in Pasadena, California and was a project engineer on MECA. He was originator of the nanoexperiment concept.

Louis Friedman is the Co-Founder and Director of The Planetary Society in Pasadena, California.

Linda Kelly is the Education Coordinator of The Planetary Society in Pasadena, California and directed their involvement in the MECA Student Nanoexperiments and SNOOPY.

Jeffery Oslick, formerly of The Planetary Society, organized the student competition for the MECA Student Nanoexperiment Challenge.

Kevin Polk, formerly of The Planetary Society, organized the construction of the MECA Student Nanoexperiments and communications with the student finalists.

Lucas E. Möller is a student at Moscow Junior High School, Moscow, Idaho and is the designer of the Angle of Repose nanoexperiment.

Kelly Trowbridge is a student at Lansing High School, Lansing, New York and is co-designer of the Contradistinctive Copper nanoexperiment.

J.essica Sherman is a student at Lansing High School, Lansing, New York and is co-designer of the Contradistinctive Copper nanoexperiment.

Adam Marshall is a middle school student in Chapel Hill, North Carolina and is co-designer of the Spacesuit Materials nanoexperiment.

Andre Luis Diaz of São Paulo, Brazil is a co-designer of the Spacesuit Materials nanoexperiment.

Anna Waldron is an education specialist at Cornell University and is an advisor to Kelly Trowbridge and Jessica Sherman.

Collin Lewis is an engineer at Visionary Products, Inc. and performed the mechanical design of the integrated SNOOPY Payload.

Csaba Gyulai is an engineer at Visionary Products, Inc. and coordinated VPI's collaboration in the MECA Student Nanoexperiment Challenge and SNOOPY.

George Powell is the founder of Visionary Products, Inc. and formerly an engineer at the Jet Propulsion Laboratory.

Thomas Meloy is a professor of engineering at West Virginia University and was the Principal Investigator of MECA.

Peter Smith is a research scientist at The University of Arizona and was the Principal Investigator for the Robotic Arm Camera for the Mars Surveyor 2001 Lander.

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